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Fatiguing effect of multiple take-offs and landings in regional airline operations

Kimberly A. Honn[a,c,*], Brieann C. Satterfield[a,c], Peter McCauley[a], J. Lynn Caldwell[b], Hans P.A. Van Dongen[a,c]

[a] Sleep and Performance Research Center, Washington State University, PO Box 1495, Spokane, WA 99210, USA
[b] Naval Medical Research Unit Dayton, Wright-Patterson Air Force Base, OH 45433, USA
[c] Elson S. Floyd College of Medicine, Washington State University, PO Box 1495, Spokane, WA 99210, USA

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ABSTRACT

Fatigue is a risk factor for flight performance and safety in commercial aviation. In US commercial aviation, to help to curb fatigue, the maximum duration of flight duty periods is regulated based on the scheduled start time and the number of flight segments to be flown. There is scientific support for regulating maximum duty duration based on scheduled start time; fatigue is well established to be modulated by circadian rhythms. However, it has not been established scientifically whether the number of flight segments, per se, affects fatigue.

To address this science gap, we conducted a randomized, counterbalanced, cross-over study with 24 active-duty regional airline pilots. Objective and subjective fatigue was compared between a 9-hour duty day with multiple take-offs and landings versus a duty day of equal duration with a single take-off and landing. To standardize experimental conditions and isolate the fatiguing effect of the number of segments flown, the entire duty schedules were carried out in a high-fidelity, moving-base, full-flight, regional jet flight simulator. Steps were taken to maintain operational realism, including simulated airplane inspections and acceptance checks, use of realistic dispatch releases and airport charts, real-world air traffic control interactions, etc. During each of the two duty days, 10 fatigue test bouts were administered, which included a 10-minute Psychomotor Vigilance Test (PVT) assessment of objective fatigue and Samn–Perelli (SP) and Karolinska Sleepiness Scale (KSS) assessments of subjective sleepiness/fatigue.

Results showed a greater build-up of objective and subjective fatigue in the multi-segment duty day than in the single-segment duty day. With duty start time and duration and other variables that could impact fatigue levels held constant, the greater build-up of fatigue in the multi-segment duty day was attributable specifically to the difference in the number of flight segments flown. Compared to findings in previously published laboratory studies of simulated night shifts and nighttime sleep deprivation, the magnitude of the fatiguing effect of the multiple take-offs and landings was modest. Ratings of flight performance were not significantly reduced for the simulated multi-segment duty day.

The US duty and flight time regulations for commercial aviation shorten the maximum duty duration in multi-segment operations by up to 25% depending on the duty start time. The present results represent an important first step in understanding fatigue in multi-segment operations, and provide support for the number of flight segments as a relevant factor in regulating maximum duty duration. Nonetheless, based on our fatigue results, a more moderate reduction in maximum duty duration as a function of the number of flight segments might be considered. However, further research is needed to include investigation of flight safety, and to extend our findings to nighttime operations.

* Corresponding author at: Sleep and Performance Research Center, PO Box 1495, Spokane, WA 99210-1495, USA.
E-mail addresses: kimberly.honn@wsu.edu (K.A. Honn), satterfield@vetmed.wsu.edu (B.C. Satterfield), mccauleypete@gmail.com (P. McCauley), jo.caldwell@us.af.mil (J.L. Caldwell), hvd@wsu.edu (H.P.A. Van Dongen).

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1. Introduction

Passenger-carrying domestic flights in US commercial aviation were governed, until recently, by duty and flight time regulations stipulated in Title 14 Code of Federal Regulations (CFR) Part 121. In unaugmented flight operations (comprising only the minimum number of pilots required to operate the airplane), the regulations restricted pilot duty time to a maximum of 16 h and flight time to a maximum of 8 h per duty period. These requirements were fixed regardless of the number of flight segments (i.e., number of take-offs and landings) within the duty period. New duty and flight time regulations for US domestic operations, based in part on the extant science of fatigue and safety, took effect on January 4, 2014. In these new regulations, included in Title 14 CFR Part 117, duty duration is limited as a function of duty start time and as a function of the number of flight segments in the duty period.

In the new regulations, a duty period starting between 05:00 and 06:00, for example, is limited to 12 h for between 1 and 4 scheduled flight segments, dropping stepwise to 10.5 h (a 12.5% reduction) for 7 flight segments or more. Similarly, a duty period starting between 07:00 and 12:00 is limited to 14 h for 1 or 2 scheduled flight segments, dropping stepwise to 11.5 h (a 17.9% reduction) for 7 flight segments or more. The maximum duration of the duty period in unaugmented operations varies between 9 h and 14 h depending on the duty start time. The reduction in the maximum duration of the duty period as a function of the number of scheduled flight segments ranges from 0% to 25% depending on the duty start time.

The relevance of duty start time for limiting duty duration is corroborated by established fatigue science (Roach et al., 2012; Vejvoda et al., 2014). Endogenous circadian rhythmicity produces daytime and nighttime peaks and troughs in subjective alertness and cognitive performance (Kerkhof and Van Dongen, 1996; Monk et al., 1997). Additionally, an endogenous sleep/wake-homeostatic process modulates alertness and performance as a function of time awake (Daan et al., 1984; Dijk et al., 1992). The circadian and homeostatic processes interact to generate predictable diel patterns of fatigue (Dijk and Czeisler, 1994; Gabehart and Van Dongen, in press), where the term fatigue refers to sleepiness and performance impairment (as is common practice in operational settings; see Satterfield and Van Dongen, 2013). In this context, regulating maximum duty durations as a function of start time to help mitigate fatigue and improve safety makes sense (Van Dongen and Hursh, 2010), especially in daytime-oriented operations (additional complexities limit the effectiveness of such regulations in nighttime operations; e.g., see Rangan et al., 2013).

The fatigue science pertaining to number of segments flown is not as well developed. Most of the literature on aviation and fatigue has focused on long-range and ultra-long-range flights (Holmes et al., 2012; Gander et al., 2014) rather than short-range, multi-segment operations. Limited evidence pertaining to short-range flight operations comes from field studies, in which pilots' subjective ratings of fatigue were found to increase with the number of segments flown in the duty period (Powell et al., 2007, 2008). In these studies, duty schedules and operational conditions were not standardized, leaving too many potential confounds to be able to draw conclusions regarding the fatiguing effect of flying multiple segments per se. No objective data pertaining to fatigue in multi-segment, short-range operations have been published. Still, it stands to reason that there may be a fatiguing effect of flying multiple segments in a duty day – in particular, a fatiguing effect of multiple take-offs and landings. These critical phases of flight are arguably the most safety-sensitive, and they typically have the highest task load (Hoermann et al., 2015).

A systems biology view of the brain mechanisms underlying cognitive impairment due to fatigue (Van Dongen et al., 2011a) posits that the effect of fatigue on alertness and performance is neuronal circuit use-dependent, and is thus predicted to be a function of task load. This prediction has been confirmed in laboratory studies, which have shown that increased task load accelerates the degradation of subjective alertness and cognitive performance due to circadian rhythm and sleep loss (Van Dongen and Dinges, 2007; Goel et al., 2014). Yet, the effect of increased task load on alertness and performance in the laboratory appears to be modest in magnitude, and it is a priori unclear to what extent it translates to a significant effect of multiple take-offs and landings in real-world operations.

The objective of the present study was to help fill this science gap. In active-duty regional airline pilots, we compared the effect of fatigue on alertness and performance between a duty schedule containing multiple segments and a duty schedule containing only a single segment. Duty start time and duration were held constant, and the order of conditions was randomized and counterbalanced, with pilots serving as their own controls. The duty periods were carried out using a high-fidelity, moving-base, full-flight simulator. This enabled us to standardize and account for other fatigue factors commonly encountered in real-world commercial aviation (e.g., air traffic density, weather, schedule delays), while retaining a high degree of operational realism. Here we report the first objective data pertaining to the fatiguing effect of multiple take-offs and landings in regional airline operations.

2. Experimental design and data analysis

2.1. Subjects

Twenty-four active-duty pilots – 12 captains (CAs) and 12 first officers (FOs) – of a US commercial regional airline were randomly recruited from among the airline's lineholder pilots certified to fly the Bombardier CRJ-200 regional airplane. One lineholder pilot scheduled for the study became unavailable and was replaced by a reserve. The pilots were 33.2 years old on average (range 24–49), and the sample included two women. The CAs had an average of 9688 h of total flight experience and 5979 h of CRJ-200 flight experience; the FOs had an average of 2829 h of total flight experience and 1475 h of CRJ-200 flight experience. The participating pilots were domiciled on the east coast of the US. On the day prior to the study, they were flown (deadheaded) to Charlotte, NC, where the study took place.

The study was approved by the Institutional Review Board (IRB) of Washington State University. All pilots gave written, informed consent. Data collected from the individual pilots were kept confidential and were not shared with the airline or any other parties besides the research team.

2.2. Experimental design

2.2.1. Simulator flights

The 24 pilots formed 12 flight crews, each comprised of one CA and one FO. Each crew flew a high-fidelity, moving-base, full-flight simulator (CAE Inc., Saint-Laurent, Québec) of the CRJ-200 regional jet airplane (Bombardier Inc., Montréal, Québec). Under the control of a simulator operator – a flight instructor who did not intervene with regard to the pilots' flight performance – two different flight schedules were simulated. One schedule was a 9-hour, multi-segment duty day in which pilots flew 5 short segments, from St. Louis, MO (STL) to Springfield, IL (SPI), to Dallas, TX (DFW), to Corpus Christi, TX (CRP), to Houston, TX (IAH), and lastly to Little Rock, AR (LIT). The other schedule was a 9-hour, single-segment duty day in which pilots flew from Miami, FL (MIA) to Seattle, WA (SEA). The airports in these schedules are associated with class B airspace representative of large airline hubs and smaller satellite